Public Service Commission of Wisconsin
Staff White Paper Report

Measurement Protocols – Facts and Misconceptions

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1. Purpose

It has come to the attention of the Public Service Commission (PSC) staff that some purported 'stray voltage investigations' are producing large amounts of numbers and charts that may not be representative of the true data required of a proper stray voltage investigation. This activity has lead to much confusion and conclusions that may be invalid based on the known laws of physics and electricity. When acquiring data, the stray voltage investigator needs to use a wide variety of techniques and specialized instruments specifically designed to gather and sometimes record information electronically. Each step of the data acquisition process is part of an overall protocol to acquire accurate, reliable, and repeatable data. Each such instrument has specific target data that it is best designed to capture and therefore must be used in a manner consistent with its design. The PSC has worked in conjunction with utilities and UW research staff for many years to develop testing methodologies (protocols) that ensure comprehensive measurements are made. We have also, in conjunction with the UW College of Agriculture and Life Sciences outreach program, developed stray voltage courses that detail the proper actions involved in the data acquisition process. This letter will explain many of the concepts and concerns we have with proper data acquisition procedures and with measurement techniques that will assure us that acquired data is valid.

Electrically derived information usually consists of a desirable *signal* content, which is directly related to a particular phenomenon of interest, and an unwanted component usually termed *noise*. Noise may be defined as any part of the observed data that is not desired. Electronic measurement systems are assemblages of instruments and components, both active and passive, interconnected to perform an overall measurement function. Each part of this system must not only carry out its individual functions properly, but must also work effectively and compatibly with all other parts comprising the entire system. Individual components must not interfere with or degrade the performance of other parts of the system. This requirement points out the importance of ensuring that proper *interfacing* exists between the various apparatus making up the system. Interfacing is defined as the joining of components in such a manner that they are able to function in a compatible and coordinated fashion. It is important for us to appreciate the basic distinguishing characteristics of both signals and noise that allow measurement systems to be set up that can discriminate against the noise components in favor of the desired signal[1] components. It is an unfortunate fact that the world is filled with many noise sources that can interfere with data. The concept of noise as a separate phenomenon can be illustrated by the following every-day examples.

2. The Noise

For an analogy, consider a person hearing music and other audio sounds. The simplest definition of noise the general populace is familiar with can be considered "unwanted sound." But a question arises: unwanted by whom? Today's teenager walking down the street with his suitcase-sized stereo blaring its modern 'music' likes what he hears, but others (parents included) may not. The airline pilot appreciates the smooth whine of his Boeing 747 engines, but the individual over whose houses this plane is flown may resent the noise. People who live near railroad tracks often get so used to the sounds of passing freight trains that they rarely notice the noise, yet visiting friends can be quite distracted by it. Conversely, individuals driving an automobile on a road that must cross those tracks are certainly aware that hearing an on-coming train, and recognizing the noise for what it is, can be a beneficial and indeed life-saving safety measure. It is generally accepted that a person's perception of audio noise depends on the characteristics of the sound: characteristics such as loudness, timbre, frequency or spectral content and whether it is customary or unusual. To some extent, an individual's age, emotional makeup, lifestyle, tastes, beliefs, and other factors determine the degree of his annoyance with a particular noise. For city dwellers, acclimated to many sounds all day long, the silence (or absence of noise) of the countryside can be as unsettling as city noises are to a country dweller. Consequently for these examples, the acceptance or dismissal of audio "noise" seems to be in the "ear" of the beholder, to coin a phrase. Although the noise we are concerned with has similar properties, the case for electronic noise is different. Since we cannot hear it, we may not be aware of its presence.

3. The Signal

The basis of data acquisition is the electronic *signal*, an electrical quantity that we believe faithfully represents useful information. There are two basic types of electrical signals:

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[1] The most important signal that is desirable to collect is the cow contact (stray) voltage. Stray voltage is defined by the PSCW as a natural phenomenon that can be found at low levels between two contact points in any animal confinement area where electricity is grounded. Electrical systems - including farm systems and utility distribution systems- must be grounded to the earth by code to ensure continuous safety and reliability. Inevitably, some current flows through the earth at each point where the electrical system is grounded and a small voltage develops. This voltage is called neutral-to-earth voltage (NEV). When a portion of this NEV is measured between two objects that may be simultaneously contacted by an animal, it is frequently called stray voltage. It is the "level of concern" defined as follows that dictates the significance of the voltage at cow contact. In Wisconsin, the "level of concern" is derived from the 1996 PSC docket 05-EI-115. In that docket, the "level of concern" is defined as 2 milliamps, AC, rms (root mean square), steady-state or 1 volt, AC, rms, steady-state across a 500-ohm resistor in the cow contact area ("steady-state" is defined by the Institute of Electrical and Electronics Engineers (IEEE) as "the value of a current or voltage after all transients have decayed to a negligible value"). The State of Wisconsin deems that this level of voltage/current is an amount of electricity where some form of mitigative action is taken on the farmer's behalf, although only some small percentage of cows may actually perceive its presence. The "level of concern" is not a damage level. Instead, it is a very conservative, pre-injury level, below the point where moderate avoidance behavior is likely to occur and well below where a cow's behavior or milk production would be harmed. The "level of concern" is further broken down into two parts. The first part is a 1-milliamp contribution from the utility, at which level mitigative action must be taken by that utility to reduce its contribution to below the 1-milliamp level. The second part is a 1-milliamp contribution from the farm system, at which level mitigative action should be taken by the farmer.

analog and digital. In analog signals, some continuously variable aspect of the electrical quantity represents the desired information. In amplitude modulated (AM) radio transmissions, for example, the amplitude, or strength, of the electromagnetic radio wave is proportional to the amplitude of the signal (the volume of the sound) that the radio wave carries. (The frequency difference between the received signal at any instant of time and the carrier frequency (channel) is the frequency of the audio sound reproduced in the speaker.) The greater the amplitude of the radio wave, the louder the sound that radiates from the radio speaker. In contrast, digital signals use standardized pulses to represent numbers. With a digital audio signal, both the frequency and volume of the signal for a set amount of time is converted to numbers represented by, for example, 16 pulses of fixed duration and amplitude. This digitized audio signal is transmitted as a stream of such 16-pulse codes that are converted back in the continuous audio signal heard from the speaker. Each of these types of signals is subject to noise interference, but in different ways. The presence of analog noise makes the separation and extraction of the analog signal more difficult and in some cases noise can be mistaken for signal if it has the same amplitude and frequency. On the other hand, digital noise usually transmutes one coded number into another so that successful recreation of the original data is usually impossible. For signals to be useful, one must try to selectively receive a desired signal over all the other signals (man-made or otherwise). To tune out other radio or television stations also received by a single antenna for instance, special filter circuits are frequently used. Such filters strongly reduce the electronic information at all frequencies except the one frequency of interest, preventing interference among different channels in a receiver. However, in addition to the desired signal that is filtered and received, a certain amount of noise at or about the same frequency is also received. Additional circuitry must be employed to separate the signal from the noise. The issue of extracting data from noise must be dealt with on a case-by-case design basis depending on the desired end results. As in life, more effort generally produces better results. Stray voltage signals are also subject to noise and interference.

4. Signal to noise ratio

Noise and interference concern most aspects of the engineering profession. In the broadest sense, noise is any error that affects the proper and desired response of a measurement procedure. Some noise issues are intrinsic to the specific devices selected to do the job. In most cases, the worst enemy is the noise brought in by the real-world environment that surrounds our data acquisition equipment. This environment includes association with nearby power lines, other electronic equipment, components, wires and cables, external transmitters, the climate, the planet Earth, the cosmos in general, and sometimes even the topology or juxtaposition of the equipment and circuits involved. Some sources of electronic noise that are relatively easy to control in a laboratory environment may be difficult to control in the farm environment. It becomes necessary to know as much detail as possible about the expected signal so that proper noise abatement or reduction techniques can be employed in the data acquisition process. Our particular situation is even more perplexing as the signal we are concerned with is a 60-Hz voltage or current at levels that other professional data acquisition practitioners might consider noise. The cow contact signal does, however, contain noise from external sources. It is a problem of relative size.

Consider the following example: a TV video signal is 1,000 times greater than the noise level. This provides a sharp television picture that is highly desired. If the signal is reduced to 100 times the noise level, the picture will be slightly "snowy" instead. If the signal is only 10 times the noise level, the picture may be totally unrecognizable – as if the TV station was not even in existence. Obviously, an important concept to be aware of is the value of having a signal significantly different from (read that as: greater than) the noise. This is known as the signal-to-noise (S/N) ratio. When a digital multimeter (DMM) is used to measure a voltage, the current from the measurement point must follow the DMM leads. If the leads also couple to an electric field or changing magnetic field, the DMM measures an induced voltage from that field as well as the potential voltage drop between the points of measurement. If the signal voltage at the point of measurement is in the same range as the induced voltage, the reading may appear to be twice what the true measurement should be. The ratio of the measured signal to the coupled noise is not often easily controlled. It takes an extra effort in the measurement process to discriminate between the signal and the noise. Unfortunately, the following two themes are so obvious that they are frequently forgotten, ignored or down-played, at least in the field:

1) Electrical interference (noise) will always occur: it is the norm.
2) Electrical interference is often most easily and cost-effectively removed at or close to its source.

Where very long leads are involved, such as associated with telephone and power line measurements, one to five kiloHertz may be considered a high frequency. In low frequency systems (< 1 kHz), S/N ratios of 60dB (deciBels) or more are desirable to effectively give the engineer enough "head-room" to most easily and cost-effectively extract the signal from the noise.[2] The presence of significant noise in data can render that data meaningless. In some recent data acquisition projects on many farms, there seems to be no differentiation between what is the signal and what is the noise. Even more to the point, the data that is gathered seems to consist only of the background noise with no specific signal detected or even expected. As anyone who has worked in the data acquisition field for long knows, background noise is omnipresent and will be the only measurable voltage to appear in the absence of signals. It is usually the lowest level of voltage present and will appear with all measurements. There is no absolute zero in a real-world measurement. Even shorting the leads of a DMM or oscilloscope together may show that some very small voltage (offset) is still present in the reading. The only useful signal that the stray voltage investigator should be concerned with is the voltage measured at a properly defined cow contact using a 500-Ohm resistor. This voltage signal arises from the electrical system's neutral conductor (both on the primary system and/or the secondary system). This is strictly a 60-Hz, rms, steady-state measurement. All other measurements traditionally gathered by stray voltage investigators are made in support of this measurement in an attempt to find the appropriate source of the cow contact voltage. Any interference signals associated with this measurement should be acknowledged for what they are – just noise.

[2] 60 dB is a 1,000:1 voltage ratio.

5. Noise and interference sources

No measurement process is perfect. There are always uncertainties in measurements that may arise from several different sources or from one predominant source. One must optimize the measurement procedure in order to minimize the uncertainties. It is important to appreciate the basic distinguishing characteristics of signals and noise that allow measurement systems to be set up that can discriminate against the noise components with respect to the signal components. The signals of most interest in the stray voltage area have been discussed above. The following is a list of possible major noise or interference sources that may couple to those signals:

1). Low frequency internal noises
2). Harmonic distortions
3). Induced radio frequency (RF) signal interferences
4). Random line frequency interference.

To help understand the nature of these source listed above, examples of typical noises and interferences are explained in the following paragraphs.

Major low frequency internal noise sources are: Johnson or thermal noise, shot noise from all solid-state amplification devices, and flicker or 1/f noise from solid-state devices. The most important one is the Johnson noise that occurs due to the random jiggling of the atoms in a physical substance. An example of Johnson (thermal) noise in a resistor is given by a well-known formula[3]: For a 1.0 MegOhm oscilloscope input resistor, at a room temperature of 25°C (= 298°K) and a bandwidth of 100 MHz, the rms noise voltage would be:

the square root of ($4 \mathbf{x} 1.38 \mathbf{x} 10^{-23} \mathbf{x} 298 \mathbf{x} 10^{6} \mathbf{x} 10^{8}$)

= the square root of ($1644.96 \mathbf{x} 10^{-9}$) = 1.28 mV rms = **3.6 mV pk-pk.**

That is a very measurable broadband noise value. It is not insignificant and it arises merely from the fact that this one single resistance is not held at absolute zero temperature. It is purely a noise source and has no signal content. Imagine the combined noise voltage effect of all the many dozens, hundreds, or thousands of resistances in a complex data acquisition system! (Compare this with a noise value of 0.00045 mV peak-to-peak for a 500-Ohm resistor at 3,000-Hz bandwidth.[4]) Since this voltage arises from the oscilloscope input resistance, there is no way of preventing it from being associated with any signals received – the two are absolutely inter-linked. Recent claims by some stray voltage investigators have implied that a few milliVolt peak-to-peak signals 'measured' on farms are somehow problematic. These are about one quarter of the voltage of a noisy resistor and are typical of commonly measured noise levels. They are not signals and can have no adverse impact on any system since these levels exist everywhere merely due to the ambient temperature making certain atoms vibrate. It is consequently a given fact that a valid signal should be many times greater than this level to be considered significant and not "buried in the noise."[5]

[3]
$$\overline{\mathbf{Vrms}} = (\mathbf{4kTR\Delta f})^{\mathbf{1/2}}$$

Where k is Boltzmann's constant (1.38×10^{-23} J/°K), T is the temperature in degrees Kelvin, R is the resistance in Ohms, and Δf is the bandwidth of interest in Hertz

[4] Nearly 8,000 times smaller!

[5] To be accurate, true *signals* of similar amplitude, from broadcast sources for instance, *can* be extracted from this type of noise, but a considerable amount of data acquisition system design effort and additional pieces of equipment are required to do so.

Harmonic distortions can be characterized as integer multiples of the fundamental frequency being acquired. They are usually much smaller in amplitude than the basic 60-Hz fundamental frequency and the sum of all these harmonic voltages appears in conjunction (added) with the fundamental signal. These frequencies are never found in the natural setting "by themselves" – that is to say, a 3^{rd} harmonic of 180 Hertz is not measured alone unless it has been purposely extracted by electronic means from the 60-Hertz power frequency signal of which it was an integral part. The highest harmonic frequency of interest is generally regarded as the 50^{th} harmonic, which has a frequency of 3,000 Hz. This is the highest frequency a power distribution system is likely to generate. Any continuous frequency greater than 3 kHz measured on the metallic elements of the distribution system is an induced voltage from an external source and is on the metal by the same mechanisms as it is on a metallic antenna. Integer multiple frequencies above this 3 kHz limit cannot be considered as arising from the power system. Signals at frequencies other than exact integer multiples of our basic 60-Hz power are, by definition, not harmonics and as a consequence must arise from sources outside of the power distribution system. In power systems, harmonic measurements are part of a power quality investigation and are covered by the IEEE 519 guideline adopted in the new PSC Ch. 113 administrative rules. Power quality voltage measurements are made from phase to phase or phase to the grounded neutral and not from the grounded neutral to a remote earth reference point. This is because the remote point contains many noise components at frequencies similar to those associated with the power system, but not originating from that system. This would render voltage measurements made to remote reference meaningless. These measurements are made only at the point of common coupling for each customer. Power quality investigations and stray voltage investigations are two separate and distinct entities and should never be confused with one another. Research at Cornell University indicates that cows are not specifically sensitive to individual harmonic voltages when they exist, but to the summation of the fundamental and all harmonics, i.e., the fundamental plus the total harmonic distortion (THD) measured as peak-to-peak. Cow contact voltages, measured by stray voltage recorders used by most utilities in Wisconsin, include all harmonics up to the 50th. In most of the cases that the PSC has reviewed, the measured voltage including THD at cow contact is within 1-2 % of the fundamental alone. Regardless of the harmonic contribution, a true-RMS reading will include the harmonic voltages. The data acquisition equipment used by utilities today takes the total signal value into account.

Induced RF signal noises may come from radio stations, television stations, cell phones, pagers, walkie-talkies, aircraft, watercraft, global positioning systems (GPS), satellite dish systems, arcing, welding, industrial processes, radar systems, X-rays and cosmic radiation, etc. They are characterized by an electric field component and their strength can be measured across two conductive points with an appropriate DMM. When the length of a lead to an instrument approaches multiples of one half of the wavelength of an RF signal, it is most easily coupled in to the measurement. For 60 Hz signals, one half wavelength is 2.5 million meters (over 1550 miles). This is not a problem. Fifty foot leads are a one-half wave receptor for about 10 MHz signals[6]– easily received by 100 MHz-bandwidth oscilloscopes. It is important to note that the Earth itself is an integral component of most communication systems at FCC-assigned frequencies from 10 kHz to 3 MHz[7] and that the intended propagation path for many of these signals from the transmitter to the receiver includes a "ground wave" component, as well as an "air wave" component. The Earth will contain arbitrary energies from all these RF sources. Electro-magnetic field strength will generally be proportional to the original power output (wattage) of the transmitter and inversely proportional to the distance from its source. The possible strength and availability of these sources is easier to understand by the following statistics. The maximum radiated power allowed for AM-radio stations is 50,000 Watts, for FM-radio stations is 100,000 Watts, and for TV stations is 5,000,000 Watts. There can be many of these signals present at a particular measurement site, for example there are at least 74 AM radio stations, 129 FM radio stations, and 43 TV stations within 150 kilometers radius (92 miles) of Madison, WI with a daytime broadcast power of nearly 70,000,000 watts in the frequency band of 0.54 to 800 MHz. Some of these interference noise signals are generally continuous while others are randomly intermittent. One example of an intermittent RF signal is the discharge electric shock you receive when you shuffle your feet across a carpet in the winter and touch a doorknob. This may produce a 10,000-Volt discharge through your 1,000-Ohm body resistance lasting 10 microseconds. An induced 'snapping' noise can be heard simultaneously on a nearby radio playing a soft music passage. You may think this discharge contains more energy than a typical alkaline D-cell, but in fact the discharge has about 1 joule of energy and the D-cell over 12,000 joules of available energy. Connecting a reference probe to ground for wideband voltage differential measurements via long unshielded leads will certainly introduce a variety of unwanted noise voltages containing different frequencies and amplitudes from these sources into the measurement.

6. Coupling mechanisms

There are five physical mechanisms by which noise interferences may be coupled into data acquisition systems:

1. Capacitive (electrically) coupled.
2. Inductive (magnetically) coupled.
3. Electro-magnetic (EM) RF coupled.
4. Conductively (hard wire) coupled.
5. Ground loop (common mode) coupled.

These coupling mechanisms may all be acting at one time on a particular measurement so determining the source of a specific signal or noise can rapidly become extremely difficult.

Some "data" has recently been acquired using a high input impedance, high bandwidth oscilloscope. Oscilloscopes are generally used in a single-ended data acquisition mode. The problem with single-ended input circuits is that the cable shield or grounded side of the signal

[6] There is a very strong 10 MHz, 10 kiloWatt AM broadcast station in Ft. Collins, CO known as WWV that broadcasts the exact time of day via voice and coded tones in a specialized format derived from the National Institute of Science and Technology (NIST) atomic clock at that site. This is a distance of over 1,000 miles from Madison and yet is easily tuned in by an appropriate radio receiver.

[7] This band contains signals from navigation, maritime mobile, aeronautical, AM broadcast, amateur and both fixed and mobile terrestrial radio sources.

input is part of the signal path. This path has a non-zero impedance and any noise voltage developed across this path adds full force to the signal. This is known as common-mode noise. The shield, if used, is part of the grounding system. A true differential input fed from a properly-created, shielded, twisted-pair cable decreases the effect of any noise that is coupled in via the shield. For all cow contact measurements at or about 60 Hz, the 500-Ohm resistor must be used. If accurate analysis of other frequencies (> 1 kHz) is desired, a "Cornell cow" load could be used.

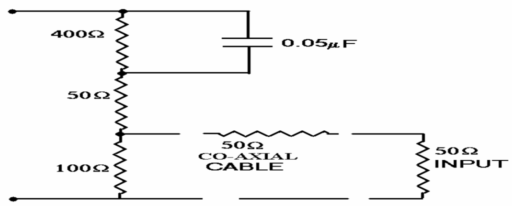

Fig. 1 Cornell Cow Circuit

Electrical circuit analysis reveals that the Cornell cow approximates the 500-ohm resistor for frequencies at or near 60 Hz and has an appropriately-reduced matching impedance for higher frequencies. This lower impedance ensures maximum signal transfer to the measuring instrument with minimal reflections.

7. Grounds and currents in the earth

The concepts of ground and grounding are basic and integral concepts utilized in the design of electrical measurement systems like the oscilloscope. Engineers have invented words like 'clean ground' or 'analog/digital ground' - concepts not taught in any textbook. They are an invention made in the frustration of trying to find an answer to the basic problem of noise. Many decades of design effort and millions of successful products have shown that ungrounded or 'floating' systems tend to be electrically noisier than grounded systems. Since all measurements of potential difference (voltage) are relative, the voltage level of any point must always be compared to some reference level. Usually this reference level is assigned a voltage value of zero and is known as the *circuit ground* or *common point* of the system. To provide one common and convenient reference potential for the majority of measurements, the potential of the Earth itself was chosen as zero. This point is always readily available but based on the discussions above, nearby earth points will not be at zero volts for all times and for all frequencies. The soil of the Earth contains water and electrolytes which together conduct currents easily so the impedance of this 'earthing' connection is kept relatively low and currents which enter the earth are easily contained therein.

Capacitively coupled interference signals at 60 Hertz can be appreciable in varying degrees of severity in nearly every measurement situation. In fact, 60-Hertz noise coupled in by this means is so pervasive that it is given its own name ---- hum. Ground loops are most easily created whenever the ground conductor of an electrical system is connected to the ground plane of the earth at two different points (the low resistances involved are ignored in this illustration).

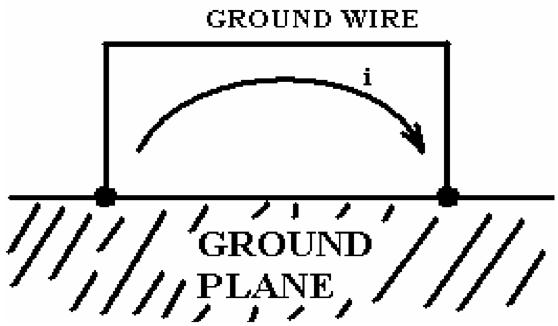

Fig. 2 A Simple circuit to illustrate a "ground loop"

Since a ground loop has a relatively large area and very low impedance, inductive pick-up from stray EM fields in the measurement environment can occur quite easily. A ground loop may act as a 'transformer secondary' and receive noise source signals via currents induced by changing (AC) magnetic fields emanating from nearby power system conductors. The power transfer ability of these induced currents, however, is usually, but not always, low. Orthodox shielding methods are not as effective against inductive pick-up in ground loops because the shielding conductors and the ground plane are themselves part of that loop. As per the example above, any conductor can act as an 'antenna' for the pick-up of electromagnetic interference, which is ever-present. It is certainly important not to confuse this noise with a meaningful signal. Much of the interference occurring in measurement systems is of discrete frequencies, for example, the pick-up of 60 Hz hum from AC power systems or the transient keying of near-by cell phones and pagers. Other examples of this interference are electrical discharges (lightning, ignition systems, relay arcing, capacitor bank switching, electric motor brushes, etc.) and RF signals (AM and FM radio, pagers and cell phones and TV) transmitted via EM waves. The sensitivity of a wire or component to this interference is roughly proportional to its length and cross-section, the resistance to ground at that point and the amplification following the input. Another example of coupled interference is the noise from your instrument's own power supply. If is it connected to the 60 Hertz mains supply, it is the nearest source of such noise. Most data acquisition instruments manufactured today have a non-linear solid state switching power supply that creates noise distortion (harmonics) on the AC circuit it is plugged in to. One has to take great care to not measure this voltage distortion as a remote signal.

The electrical power distribution systems that supply our electric power use earth ground as their reference. This connection is also an absolute necessity for reasons of safety. Electrical power systems conduct enormous amounts of energy to all the corners of the continent. We are in constant proximity of this power and human safety must be paramount in the power system design. As a natural result, currents flow in the earth from these systems. These earth currents are inescapable, but are not mysterious. They must obey the laws of physics. Once a ground current (from an electrical neutral/ground system) enters the earth, it becomes an 'earth current' and it can no longer be distinguished separately from the many other currents in the earth. The current is 'pushed' into the earth by some voltage above the nearly zero potential of the earth at that point and will be extracted from the earth by a connection to the driving source where it must return to satisfy the "conservation of energy' law, Ohm's Law and Kirchhoff's Law. It is commonly believed that current follows the "path of least resistance" as if electrons had brains and voted on which path to take!! The truth is that current takes all paths available to it in inverse proportion to the resistance of the path. Because power systems are used so extensively throughout the planet, it can be assumed that these earth currents (at 60 Hz) flow almost everywhere. Such currents will cause a measurable potential drop (voltage) to exist between separate points on the earth's surface[8]. This is an easily obtainable quantity and has been in existence for commercial power systems since their inception in the early 1880's. Whatever the source of currents in the Earth, cosmic or terrestrial in origin, they are there for the long term. They, in some instances, have been around since the origin of the planet. How can something so basic to nature be suddenly problematic? If AC currents flow in any conductor (the Earth included), they always possess an unmistakable "fingerprint" – AC magnetic fields proportional to their amperage. A gaussmeter, which measures magnetic field intensity, can be used to indicate the presence, extent, and strength of any current along the surface of the Earth. If the gaussmeter detects no magnetic 60-Hz field, then no 60-Hz current is flowing at that point. If any earth current is going to affect animals on farms, it will have to be manifested as a step potential measurable via a special cow contact set-up. Normally, cow contacts are measured via a PSC protocol using a 4" square weighted copper plate, but this may be difficult to use in an open field. The Minnesota Science Advisor's field study measured step potential cow contacts using two conductive ground rods at least 2 feet into the earth and spaced about 5 feet apart. A 60 Hz, rms, steady state voltage was measured across the two rods using a 500-Ohm resistor with proper lead connections to minimize noise pick up. The same "level of concern" applies to this measurement as to any measurement at cow contact points inside a barn.

8. Source resistance and oscilloscopes

Because noise is of a fundamental nature, it must be realized that complete freedom from noise can never be achieved in a real-world measurement. Loading effects from input impedances that are not sufficiently greater than the source impedance are also important to limit unwanted modification of the desired signals. Source resistance is a part of every signal voltage and every noise voltage.

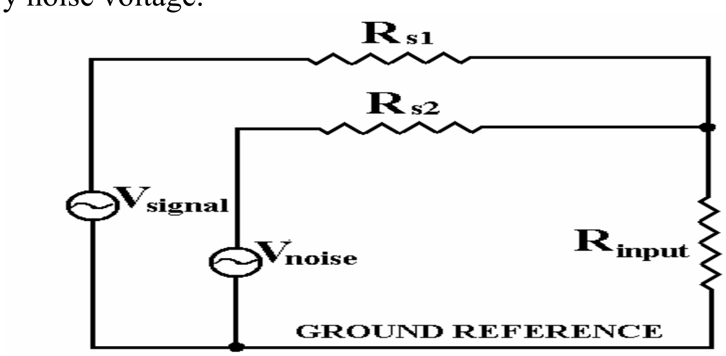

Fig. 3 Coupling circuit for noise and signal

[8] One source lists typical ranges up to 10 V. rms.

There are three types of measuring device input impedances: low, high and system.

1. Low input impedance systems are not very useful as they tend to load down the signal being measured and therefore affect the accuracy. They are characteristic of very inexpensive metering systems and are used to get ballpark rather than precision data.
2. High input impedance systems (in the range of 1 MegOhm or more) maximize the signal strength by ensuring the input impedance is much, much greater than the source impedance, thereby minimizing the loading effect. This is the best type for low frequency precision measurements.
3. System input impedance systems (like 50-Ohm or 75-Ohm) match the source impedance thereby maximizing the power transfer and minimizing reflections. This is the only type of input that is practical for very high frequency measurements (> 100 kHz).

Most measurements are made today with digital based instrumentation. One must understand the digitizing process in order to appreciate where errors and noise need to be considered. In the process of acquiring data, a digital oscilloscope, for example, converts the real-world analog data to digital data via an analog-to-digital converter (ADC). When the oscilloscope is designed, a decision is made as to what size ADC is installed. The Fluke-99B 100-MHz digital oscilloscope, for instance, has an 8-bit vertical resolution in its ADC. This means that the maximum voltage in each range setting is broken up into 2^8 or 256 parts. The most sensitive vertical setting is 1 milliVolt per division. The screen has 8 vertical divisions, so a maximum signal for this reading would be 8 mV pk-pk. Using 256 bits to represent 8 mV translates to each bit representing 0.03125 mV. This is an implied accuracy of 0.4%, but remember that the noise of the input resistor can be nearly 4 mV pk-pk (50% of the maximum signal), so the accuracy at this resolution has little meaning. A comfortable signal-to-noise ratio would have each bit representing ½ of the typical noise value. This means each bit would be 2 mV and the 256 bits would represent a full screen signal of about 0.512 V. pk-pk. This means that this instrument is best used at 100 mV/division or greater. Based on this type of error analysis, there is no need to adjust the oscilloscope to more sensitive settings. Another source of much confusion in using digital data acquisition equipment occurs when data is to be properly analyzed. The architecture of a digital device opens up some possibilities for processing (manipulating) the acquired waveform data that are not possible with the older model analog equipment[9]. With the data in digital form, the instrument's computer processor can operate on it before it is provided to the display or stored. The introduction of this data manipulation process may seem to be beneficial to the user by providing more information than was originally acquired, but without a thorough understanding of how and why the data was manipulated, a mis-interpretation of the display can easily result. One can ask the following questions: How does the display portray very fast changes in signal frequency? How does the display portray very large differences in signal amplitude? Are there internal noise filter circuits or mathematical equivalents to "pre-process" the data? How does a 'memory dump' differ from the data seen on the display? How are glitches (transient spikes) displayed? How do each of the front panel controls affect

[9] They were a WYSIWYG proposition: What You See Is What You Got.

the display? The answers to these questions must be known to properly interpret the data presented on the display.

9. Conclusions

In summary, the planet Earth is full of electrical noise. This noise has possible frequency content from less than 1 Hertz to many GigaHertz. Much of this noise and interference is from man-made sources. As long as our modern society uses electricity in all its varied forms, noise will be everywhere. It is accessible by many means and will be present in all electrical systems. Any signal measured between a system conductor and the earth can and will be influenced by this noise to some extent. Because of the various coupling mechanisms enumerated above, noise is passed along from point to point and its true origin is most often obscured in the process. All data acquisition measurements made will contain noise and interference voltages, therefore those below a reasonable level of about 20 mV are equivalent to zero and should be ignored. Stray voltage measurements at cow contact points, whether in the barn or from step potential sites, and neutral-to-earth-reference potentials need to be made as true-rms voltages (which will include both the fundamental 60 Hz and harmonic levels present). These are the only voltage signals that have been shown by knowledgeable researchers to be of concern to competent stray voltage investigators. Most other frequencies measured are from noise sources. The only exceptions are transient signals from known or discovered on-farm sources such as motor starts and stops, intermittent faults, and fencers, trainers, and crowd gate circuits. There are well-documented protocols for measuring and dealing with these particular signals. There is also a considerable research base as to what levels and frequencies of these non-steady state voltage signals are of concern to stray voltage investigators. It is obvious that the levels of noise commonly present are not problematic based on general experience and the best available research. Lastly, it is important to realize that the specific source of each noise component is not easily identifiable. The extensive Phase II testing protocol has been developed by the PSC to determine the source of only the 60-Hz steady state stray voltage signal on the farm/utility electrical system.